Ultra-structure, organization and Function of the Mitochondria

Content Type	Notes
Status	Done
Chapter	Cell - The Unit of Life, Subcellular organelles
Course	Graduation
Reference	Cell Biology by Thomas D.Pollard, From NCERT, Kerp's Cell and Molecular Biology
Subject	Biochemistry
Topic	Function, Mitochondria, Organization, Ultra-structure
Ruhul Amin	@February 15, 2023 4:10 AM
Difficulty Level	
Mistake type	
Previous Year Questions	

Mitochondria
- Evolution of Mitochondria
- Definition of Ultrastructure
- Ultra-Structure of Mitochondria
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- Compartmentization of mitochondria
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Glycolysis in detail : Step by step
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TCA / Citric Acid Cycle in detail : Step by step
Electron transport system
Must remember Key point : Ultra-structure, organization and Function of the Mitochondria
Multiple Choice Questions (Specially for NEET aspirants -from NCERT)

Mitochondria

Evolution of Mitochondria

- Mitochondria and chloroplasts both arose from endosymbiotic bacteria.
- Both mitochondria and chloroplasts retain remnants of those prokaryotic genomes.
- Both organelles brought biochemical mechanisms that allow their eukaryotic hosts to acquire and use energy more efficiently. Oxidative phosphorylation by mitochondria and photosynthesis by chloroplast.
- Bacteria and mitochondria share homologous proteins for the key steps in oxidative phosphorylation
- Plasma membranes of bacteria and inner membranes of mitochondria have equivalent components, and the bacterial cytoplasm corresponds to the mitochondrial matrix

Definition of Ultrastructure

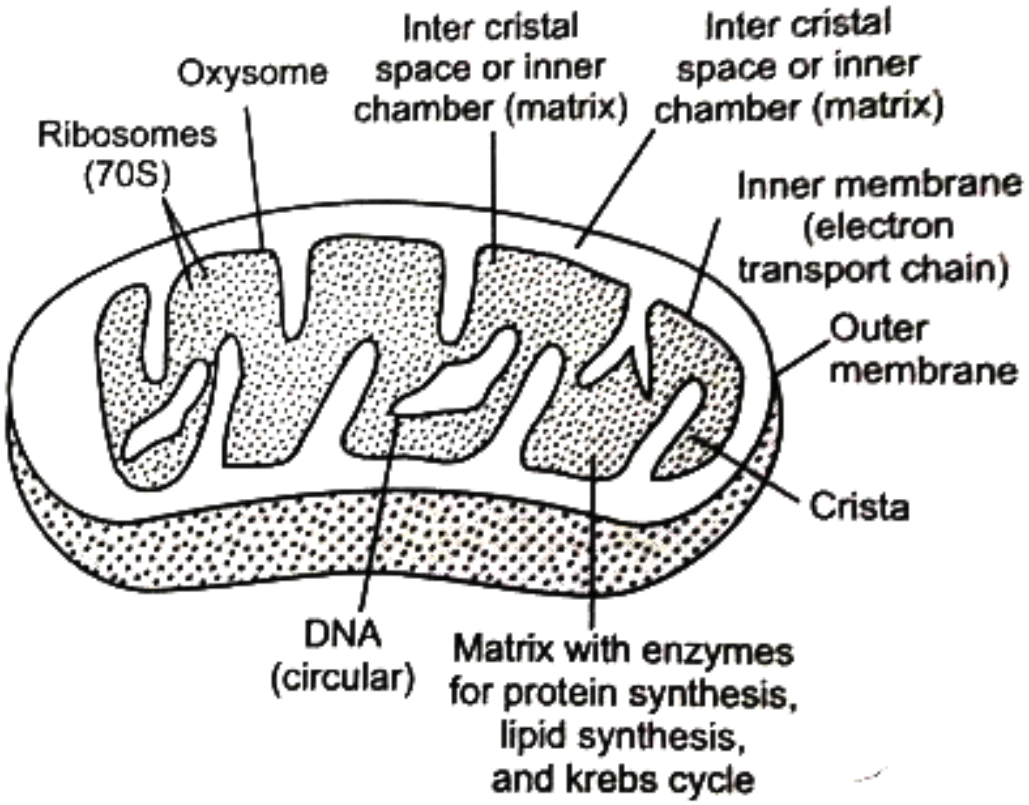
🔬 Ultrastructure: Fine structure, especially within a cell, that can be seen only with the high magnification obtainable with an electron microscope.The Ultrastructure is studied by cell fractionation technique and electron microscope. The plants cells are placed in acidic solution for removing cell wall before centrifugation.Cell fractionation is a special technique in which cells are homogenized in ultra centrifuge.Cell fractionation technique breaks the plasma membrane and separate different organelles in different layers.Each layer is removed and studied under electron microscope.

Ultra-Structure of Mitochondria

- Mitochondria consist of two membrane-bounded compartments.
- **Outer membrane** surrounds the **intermembrane space**. The **inner membrane** surrounds the **matrix**.
- Each membrane and compartment has a distinct protein composition and functions.
- **Porins** in the outer membrane provide nonspecific channels for passage of molecules of less than 5000 Da, including most metabolites required for ATP synthesis.
- The matrix is the site of fatty acid oxidation, the citric acid cycle, and mitochondrial protein synthesis.

Fatty acid oxidation:In addition to glucose, many cell types rely on fatty acids as a source of energy.Oxidation of fatty acids occurs in multiple regions of the cell within the human body; the mitochondria,peroxisome and endoplasmic reticulum.

- Highly impermeable inner membrane.
- Inner membrane has two domains. The boundary domain next to the outer membrane is specialized for protein import at contacts with the outer membranes. The rest of the inner membrane forms folds called cristae.
- **Cristae** may be tubular or flattened sacs and vary in number and shape.
- Four complexes (I to IV) of **integral membrane proteins** use the transport of electrons to create a gradient of protons across the inner membrane.
- The F-type rotary **ATP synthase** uses this proton gradient to synthesize ATP.


Inter cristal space or inner chamber (matrix)
Inter cristal space or inner chamber (matrix)
Oxysome
Ribosomes (70S)
Inner membrane (electron transport chain)
Outer membrane
Crista
DNA (circular)
Matrix with enzymes for protein synthesis, lipid synthesis, and krebs cycle

Well labelled diagram of mitochondria.

Oxysome : Key points

- The term "Oxysome" is not a commonly used term in modern mitochondrial research, but it has been historically used to refer to the protein complexes involved in oxidative phosphorylation, the process by which mitochondria produce ATP (energy) for the cell. These protein complexes are also known as the electron transport chain or the respiratory chain.
- The electron transport chain consists of five protein complexes, which are embedded in the inner mitochondrial membrane. These complexes work together to transport electrons from NADH and FADH2 to oxygen, generating a proton gradient that is used to produce ATP.

Crista (plural cristae) : Key points

- Cristae are structures in the inner mitochondrial membrane that increase its surface area, allowing for more efficient ATP production through oxidative phosphorylation.
- The shape and arrangement of cristae can vary depending on the metabolic state of the cell.

- The enzymes and other proteins involved in oxidative phosphorylation are embedded in the cristae membrane.
- Cristae have been shown to be important in the regulation of apoptosis (programmed cell death) by releasing certain proteins from the intermembrane space of mitochondria.
- Abnormal cristae morphology has been associated with various diseases, including neurodegenerative disorders and metabolic disorders.

Definition of Organization

The cell organization is the arrangement of components in a cell.The cells are minute in size, but the organization of cells is very precise.Each component called an organelle, performs a specific function vital for the cell.

Compartmentization of mitochondria

- They are compartmentalized with two distinct membranes, the inner and outer membrane.
- Each membrane and compartment has a distinct protein composition and functions.
- The inner membrane is highly folded and is called cristae, which creates a large surface area for the enzymes involved in the energy-producing reactions to take place.
- Further Inner membrane has two domains.
- The outer membrane is less permeable and encloses the entire organelle.
- This compartmentalization allows for the separation of the enzymes responsible for energy production from the rest of the cell, and allows for the creation of a

high-concentration gradient of ions that is necessary for energy production to occur.

- Additionally, it allows for the regulation of the transport of molecules in and out of the mitochondria, which is important for maintaining the proper function of the organelle.
- Understanding the compartmentalization of mitochondria is important for understanding cellular metabolism and energy production in eukaryotic cells.

Functions of Mitochondia

- Mitochondria are responsible for generating the majority of a cell's energy in the form of ATP through cellular respiration .
- Mitochondria also play a role in regulating cellular metabolism and the cell cycle, as well as in programmed cell death (apoptosis).
- Mitochondria also have their own DNA and can reproduce independently of the cell.
- Mitochondria also play a role in the regulation of calcium ions in the cell.
- Mitochondria are also involved in the synthesis of some lipids and steroid hormones.
  -Mitochondria have a role in the regulation of the immune response and inflammation
  -Mitochondria also have a role in maintaining cellular redox balance
- Mitochondria are essential for normal cellular function, and defects in mitochondrial function have been linked to a variety of human diseases.

Synthesis of ATP by Oxidative Phosphorylation

- Mitochondria use energy extracted from the chemical bonds of nutrients to generate a proton gradient across the inner membrane. This proton gradient drives the F-type rotary ATP synthase to produce ATP from adenosine diphosphate (ADP) and inorganic phosphate.
- Mitochondria receive energy-yielding chemical intermediates from two metabolic pathways, glycolysis and fatty acid oxidation.

🔬 Fatty acid oxidation:In addition to glucose, many cell types rely on fatty acids as a source of energy.Oxidation of fatty acids occurs in multiple regions of the cell within the human body; the mitochondria,peroxisome and endoplasmic reticulum.

Glycolysis

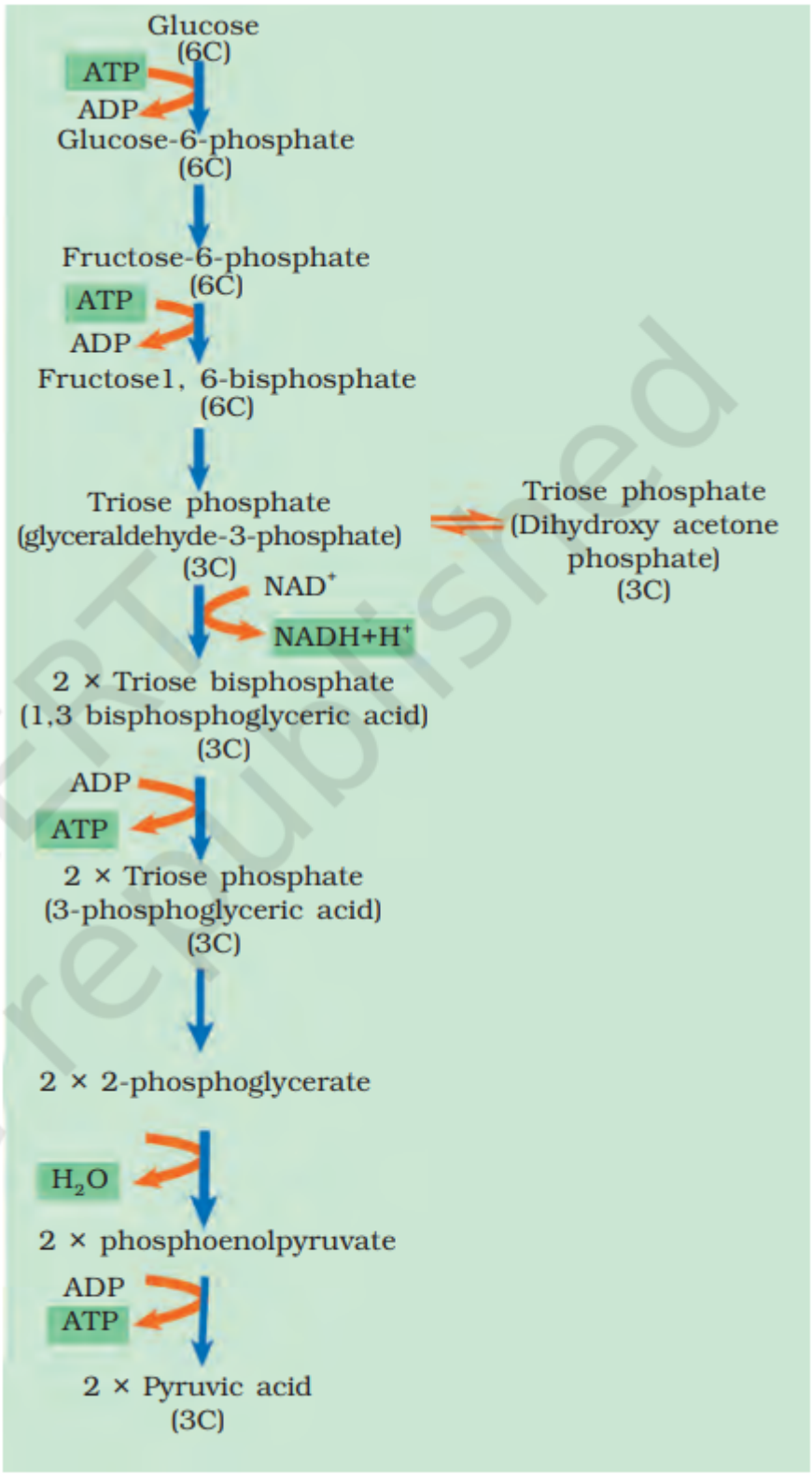
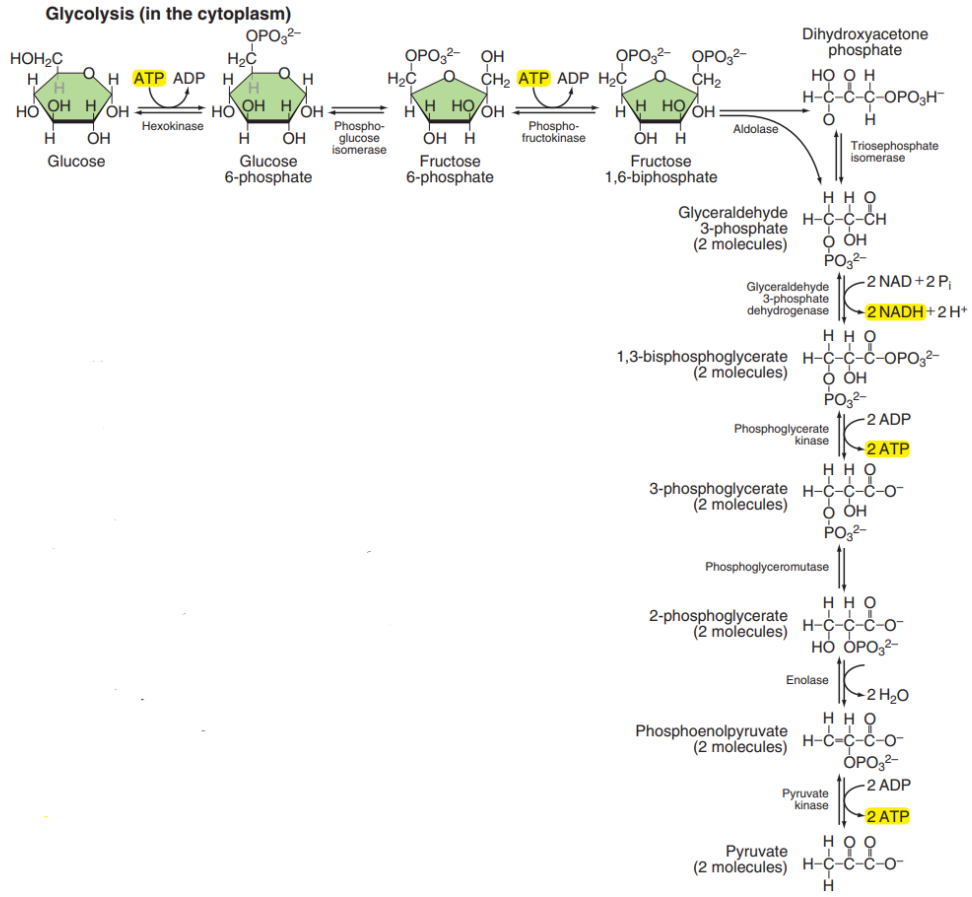


Figure 14.1 Steps of glycolysis

Glycolysis in short



Glycolysis in detail

Glycolysis in detail : Step by step

The steps involved in glycolysis:

1. Glucose is phosphorylated: In the first step of glycolysis, glucose is phosphorylated by the enzyme hexokinase to form glucose-6-phosphate. This reaction requires the input of one ATP molecule and produces ADP as a byproduct.
2. Glucose-6-phosphate is converted to fructose-6-phosphate: In the second step, glucose-6-phosphate is converted to fructose-6-phosphate by the enzyme glucose-6-phosphate isomerase.
3. Fructose-6-phosphate is phosphorylated: In the third step, fructose-6-phosphate is phosphorylated by the enzyme phosphofructokinase to form fructose-1,6-bisphosphate. This reaction requires the input of another ATP molecule and produces ADP as a byproduct.
4. Fructose-1,6-bisphosphate is cleaved: In the fourth step, fructose-1,6-bisphosphate is cleaved into two three-carbon molecules: glyceraldehyde-3-

phosphate (G3P) and dihydroxyacetone phosphate (DHAP). The enzyme that catalyzes this reaction is aldolase.

5. DHAP is converted to G3P: In the fifth step, the enzyme triose phosphate isomerase converts DHAP into G3P. The end result of this step is two molecules of G3P.
6. G3P is oxidized and phosphorylated: In the sixth step, the two molecules of G3P are each oxidized by the enzyme glyceraldehyde-3-phosphate dehydrogenase. This reaction produces two molecules of NADH and two molecules of 1,3-bisphosphoglycerate. The 1,3-bisphosphoglycerate is then phosphorylated by the enzyme phosphoglycerate kinase to produce two molecules of ATP.
7. 3-phosphoglycerate is converted to 2-phosphoglycerate: In the seventh step, the enzyme phosphoglycerate mutase converts 3-phosphoglycerate to 2-phosphoglycerate.
8. 2-phosphoglycerate is converted to phosphoenolpyruvate: In the eighth step, the enzyme enolase converts 2-phosphoglycerate to phosphoenolpyruvate.
9. Phosphoenolpyruvate is converted to pyruvate: In the final step of glycolysis, the enzyme pyruvate kinase converts phosphoenolpyruvate to pyruvate. This reaction produces two molecules of ATP.

In summary, the ten steps of glycolysis involve the conversion of glucose into two molecules of pyruvate, with the production of two molecules of ATP and two molecules of NADH.

TCA / Citric Acid Cycle

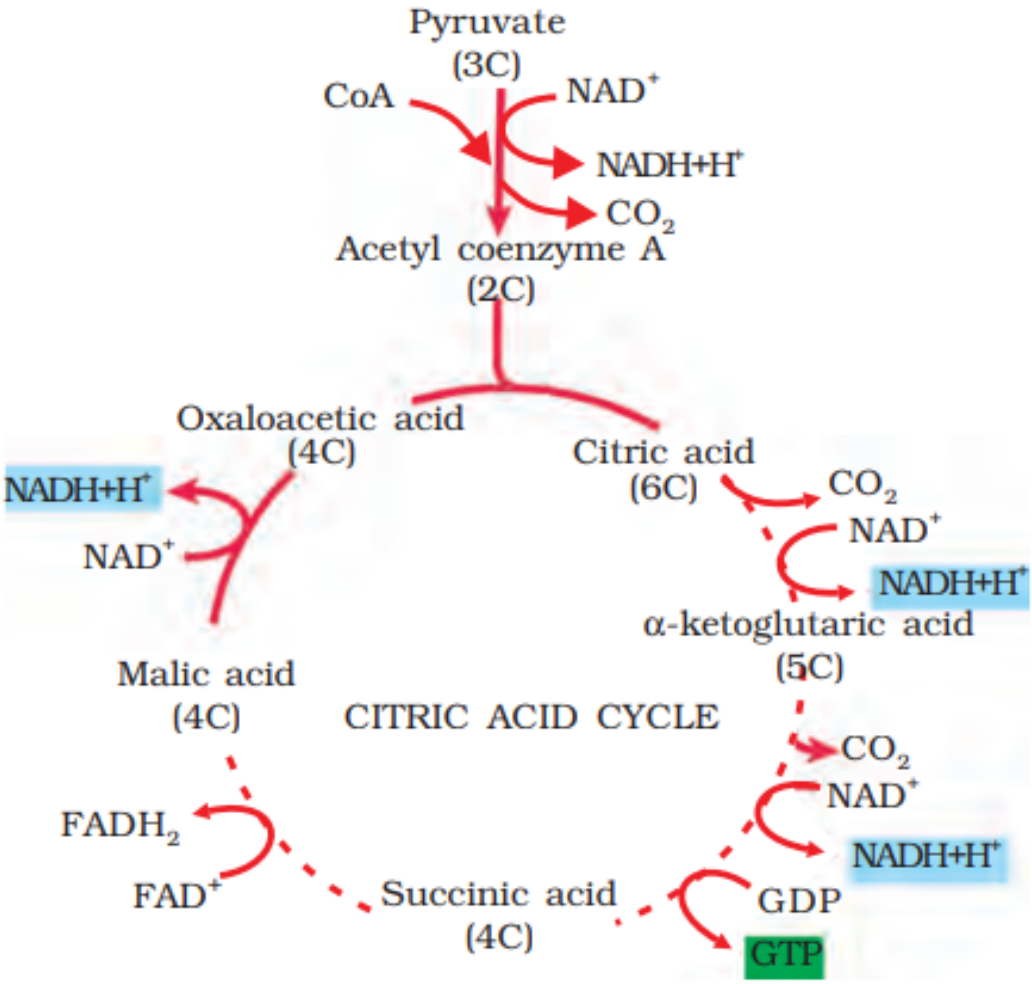
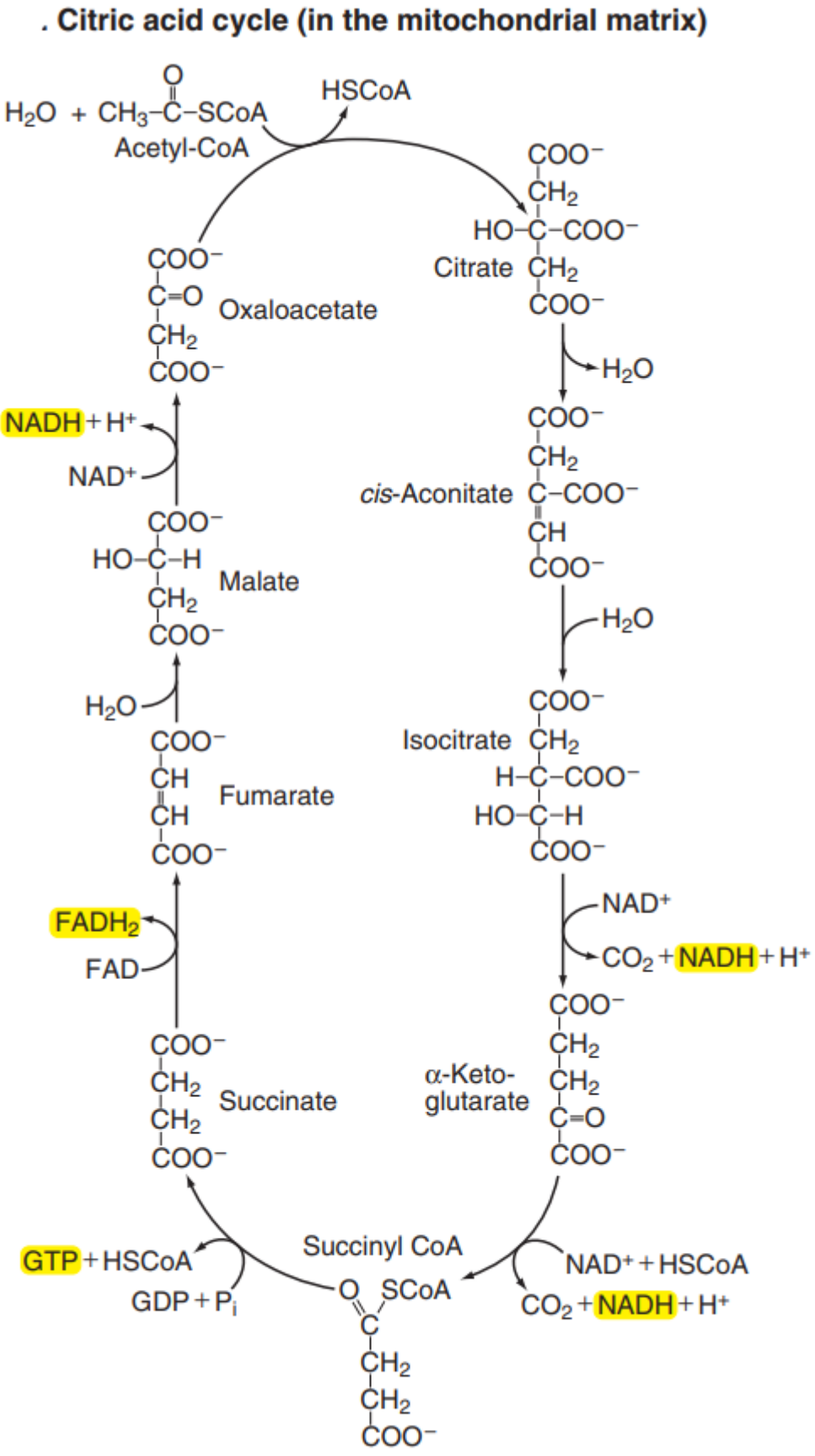


Figure 14.3 The Citric acid cycle

TCA / Citric Acid Cycle (In short)



TCA / Citric Acid Cycle (In detail)

- Breakdown of lipids yields fatty acids linked to acetylCoA by a thioester bond. Enzymes in the matrix degrade fatty acids two carbons at a time in a series of oxidative reactions that yield NADH, the reduced form of flavin adenine dinucleotide (FADH2, another energy-rich electron carrier associated with an integral membrane enzyme complex), and acetylCoA for the citric acid cycle.
- Breakdown of acetyl-CoA during one turn of the citric acid cycle produces three molecules of NADH, one molecule of FADH2, and two molecules of carbon dioxide.

TCA / Citric Acid Cycle in detail : Step by step

A detailed description of the steps involved in the TCA (tricarboxylic acid) cycle, also known as the citric acid cycle:

1. Acetyl-CoA combines with oxaloacetate: The cycle begins when the two-carbon molecule acetyl-CoA combines with the four-carbon molecule oxaloacetate to form the six-carbon molecule citrate. This reaction is catalyzed by the enzyme citrate synthase.
2. Citrate is isomerized: In the second step, the enzyme aconitase catalyzes the isomerization of citrate into its isomer, isocitrate.
3. Isocitrate is oxidized and decarboxylated: In the third step, the enzyme isocitrate dehydrogenase catalyzes the oxidation and decarboxylation of isocitrate into alpha-ketoglutarate, a five-carbon molecule. This reaction generates one molecule of NADH.
4. Alpha-ketoglutarate is oxidized and decarboxylated: In the fourth step, the enzyme alpha-ketoglutarate dehydrogenase catalyzes the oxidation and decarboxylation of alpha-ketoglutarate into succinyl-CoA, a four-carbon molecule. This reaction generates one molecule of NADH and one molecule of carbon dioxide (CO2).
5. Succinyl-CoA is converted to succinate: In the fifth step, the enzyme succinyl-CoA synthetase catalyzes the conversion of succinyl-CoA into succinate, a four-carbon molecule. This reaction also produces one molecule of ATP or GTP (guanosine triphosphate).
6. Succinate is oxidized: In the sixth step, the enzyme succinate dehydrogenase catalyzes the oxidation of succinate into fumarate, a four-carbon molecule. This reaction generates one molecule of FADH2, which is a high-energy electron carrier.

7. Fumarate is hydrated: In the seventh step, the enzyme fumarase catalyzes the hydration of fumarate into malate, a four-carbon molecule.
8. Malate is oxidized: In the eighth and final step, the enzyme malate dehydrogenase catalyzes the oxidation of malate into oxaloacetate, a four-carbon molecule. This reaction generates one molecule of NADH.

The TCA cycle is then ready to begin again with the next molecule of acetyl-CoA. In summary, the eight steps of the TCA cycle generate three molecules of NADH, one molecule of FADH2, one molecule of ATP or GTP, and two molecules of CO2 for each molecule of acetyl-CoA that enters the cycle. These high-energy electron carriers are used to generate ATP through oxidative phosphorylation in the electron transport chain.

Electron transport system

- Energetic electrons donated by NADH and FADH2 drive an electron transport pathway in the inner mitochondrial membrane that powers a chemiosmotic cycle to produce ATP
- Electrons use two routes to pass through three protein complexes in the inner mitochondrial membrane. Starting with NADH, electrons pass through complex I to complex III to complex IV. Association of these three complexes in a “super complex” may facilitate electron transfer. Electrons from FADH2 pass through complex II to complex III to complex IV.
- Along both routes, energy is used to transfer multiple protons (corresponding to at least 10 electrons per NADH oxidized) across the inner mitochondrial membrane from the matrix to the inner membrane space. The resulting electrochemical gradient of protons drives ATP synthesis
- This process is called oxidative phosphorylation, because molecular oxygen is the sink for energy-bearing electrons at the end of the pathway, and because the reactions add phosphate to ADP.
- Electrons give up energy as they move step by step along the transport pathway. In three complexes along the pathway, this energy is used to pump protons from the matrix to the inner membrane space. This establishes an electrochemical proton gradient across the inner mitochondrial membrane that is used by the F-type rotary ATP synthase to drive ATP production.
- Direction is provided to the movements of electrons by progressive increases in the electron affinity of the acceptors. The final acceptor, oxygen (at the end of

the pathway), has the highest affinity

- The first component of the electron transport pathway, complex I (or NADH:ubiquinone oxidoreductase), handles electrons obtained from NADH
- For each molecule of NADH oxidized, the transmembrane domains of complex I transfer four protons from the matrix into the inner membrane space.
- The second component of the electron transport pathway is complex II or succinate:ubiquinone reductase, a transmembrane enzyme that makes up part of the citric acid cycle. Complex II couples oxidation of succinate (a four-carbon intermediate in the citric acid cycle) to fumarate with reduction of flavin adenine dinucleotide (FAD) to FADH2. Complex II does not pump protons but transfers electrons from FADH2 to ubiquinone. Reduced ubiquinone carries these electrons to complex III
- The third component of the electron transport pathway is complex III, also called cytochrome bc1.
- Complex III couples the oxidation and reduction of ubiquinone to the transfer of protons from the matrix across the inner mitochondrial membrane. Energy is supplied by electrons from both complex I and complex II that move through the cytochrome b subunit to a subunit with a 2Fe2S redox center. This subunit then rotates into position to transfer the electron to cytochrome c1, another subunit of the complex.
- Cytochrome c1 then transfers the electron to the water-soluble protein cytochrome c in the intermembrane space (or periplasm of bacteria).
- Cytochrome oxidase, complex IV, takes electrons from four cytochrome c molecules to reduce molecular oxygen to two waters and to pump four protons out of the matrix.
- The electrochemical proton gradient produced by the electron transport chain provides energy to synthesize ATP.
- F-type rotary ATP synthase (complex V) can either use ATP hydrolysis to pump protons or use the transit of protons down an electrochemical gradient to synthesize ATP

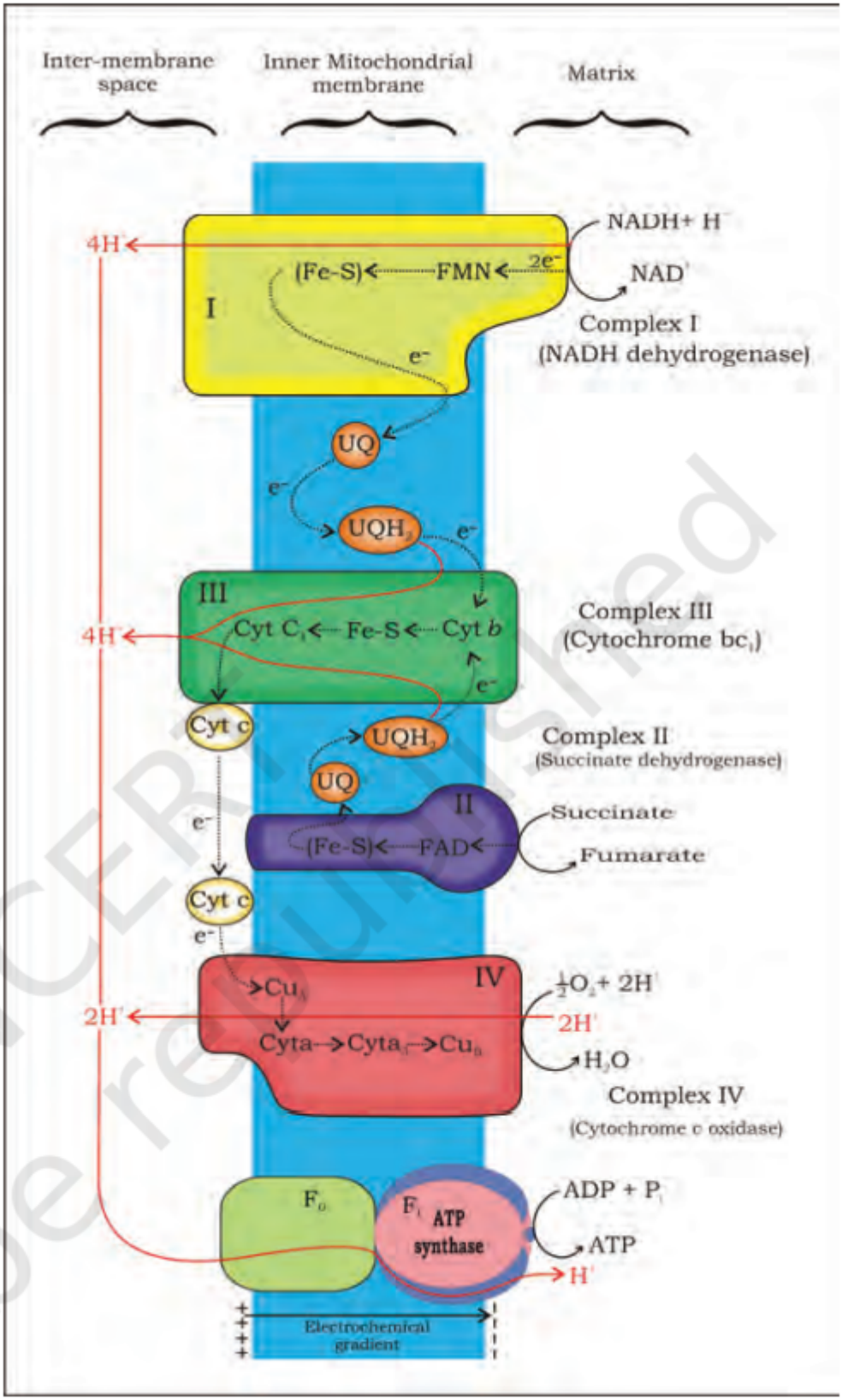


Figure 14.4 Electron Transport System (ETS)

Figure : The electron transport system of the inner mitochondrial membrane. Note the pathway of electrons through the four complexes (red and yellow arrows) and the sites of proton translocation between the matrix to the intermembrane space (black arrows). The stoichiometry is not specified, but at the last step, four electrons are required to reduce oxygen to water. The F-type ATP synthase uses the electrochemical proton gradient produced by the electron transport reactions to drive ATP synthesis. FAD, flavin adenine dinucleotide.

Must remember Key point : Ultra-structure, organization and Function of the Mitochondria

1. Ultra-structure: The mitochondria are double-membrane organelles with an outer membrane and an inner membrane. The inner membrane is highly folded into cristae, which increase the surface area available for ATP production.
2. Organization: Mitochondria are present in almost all eukaryotic cells, and their number can vary depending on the energy needs of the cell. They can also form dynamic networks and change their shape and position in response to cellular needs.
3. Function: Mitochondria are often referred to as the "powerhouses" of the cell because they produce ATP, which is the energy currency of the cell. They do this through the process of oxidative phosphorylation, which occurs in the inner mitochondrial membrane. In addition to ATP production, mitochondria are also involved in several other processes, including calcium homeostasis, regulation of cell death, and lipid metabolism.
4. Mitochondrial DNA: Mitochondria contain their own DNA, which is circular and encodes for some of the proteins involved in oxidative phosphorylation. However, most of the proteins needed for ATP production are encoded by nuclear DNA and imported into the mitochondria.
5. Mitochondrial dysfunction: Mitochondrial dysfunction has been implicated in several diseases, including neurodegenerative disorders, metabolic disorders, and cancer. Damage to the mitochondrial DNA or disruptions in the electron transport chain can lead to decreased ATP production and the accumulation of harmful reactive oxygen species.

Multiple Choice Questions (Specially for NEET aspirants -from NCERT)

Question:

Unless specifically stained by a vital stain like Janus Green, which of the following will not be visible under a microscope?

1. Rough endoplasmic reticulum
2. Smooth endoplasmic reticulum
3. Golgi apparatus
4. Mitochondria

Answer : 4.Mitochondria

Question:

Mitochondria and chloroplast are

I.semi-autonomous organelles.

II. formed by division of pre-existing organelles and they contain DNA but lack protein synthesizing machinery.

Which one of the following options is correct?

(1) Il is true but I is false

(2) I is true but ll is false

(3) Both I and I are false

(4) Both I and II are correct

Answer :(2) I is true but ll is false

Question: [NEET 2015]

Cytochromes are found in

1. matrix of mitochondria
2. outer wall of mitochondria
3. cristae of mitochondria
4. lysosomes

Answer :3.cristae of mitochondria

Question: [NEET 2007]

Select the wrong statement from the following:

1. both chloroplasts and mitochondria contain an inner and an outer membrane
2. both chloroplasts and mitochondria have an internal compartment, the thylakoid

space bounded by the thylakoid membrane

1. both chloroplasts and mitochondria contain DNA
2. the chloroplasts are generally much larger than mitochondria

Answer :2.both chloroplasts and mitochondria have an internal compartment, the thylakoid

space bounded by the thylakoid membrane

Question: [NEET 2006]

Which of the following statements regarding mitochondrial membrane is not correct?

1. The outer membrane is permeable to all kinds of molecules
2. The enzymes of the electron transfer chain are embedded in the outer membrane
3. The inner membrane is highly convoluted forming a series of infoldings
4. The outer membrane resembles a sieve

Answer :2.The enzymes of the electron transfer chain are embedded in the outer membrane

Question: [AIIMS 2001] [NOT FROM NCERT]

Extranuclear genes occurs in

1. plastids and are not inherited
2. plasmid and are not inherited
3. mitochondria and are inherited by female
4. mitochondria and are inherited by male.

Answer :3.mitochondria and are inherited by female

Question: [AIIMS 2017] [NOT FROM NCERT]

Mitochondria and chloroplast are believed to be bacterial endosymbiont because

I. they have self nucleic acid i.e., circular ds, DNA and RNAs

II. 70s ribosomes

III. their membrane resembles that of bacteria

IV. ETS and ATP forming machinery is present.

(1) I and II

(2) I, II and III

(3) All of these

(4) I and IV

Answer :(3) All of these

Question:[AIIMS 2015] [NOT FROM NCERT]

If a biochemical analysis of mitochondria has to be done, the best procedure would be

(1) select cells which have a larger number of mitochondria

(2) plasmolyse the cell and filter out the mixture and take the debris

(3) grind the cells and filter out the mixture and take the debris

(4) subject the cell to cell fractionation (centrifuge) and obtain mitochondria

Answer :(4) subject the cell to cell fractionation (centrifuge) and obtain mitochondria

Question:

Cristae is formed through

(1)infoldings of inner membrane

(2)infoldings of outer membrane

(3)through deposition of intracellular lipids

(4)All of the above

Answer :(1)infoldings of inner membrane

Question:

ETS takes place in which of the following compartment of mitochondria

1. inner compartment
2. outer compartment
3. matrix
4. Both A and C

Answer :1.inner compartment

Question:

Cytochromes are found in

1. matrix of mitochondria

2. outer wall of mitochondria

3. cristae of mitochondria

4. lysosomes

Answer :3. cristae of mitochondria

Question: [NEET 2021]

Match each item in Column I with one item in Column II and chose your answer from the codes given below:

Column I	Column II
I. Cristae	1. Flat membramous sacs in stroma
II. Cisternae	2. Infoldings in mitochondria
III. Thylakoids	3. Disc-shaped sacs inGolgi apparatus

Codes:

	I	II	III
1.	1	2	3
2.	3	1	2
3.	2	3	1
4.	1	3	2

Answer :3.